

Flow Structure Comparison for two 7-Point LDI Configurations

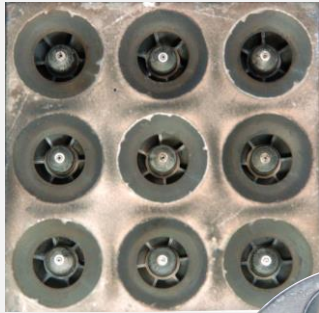
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Motivation & History—Reduce Aircraft NOx emissions



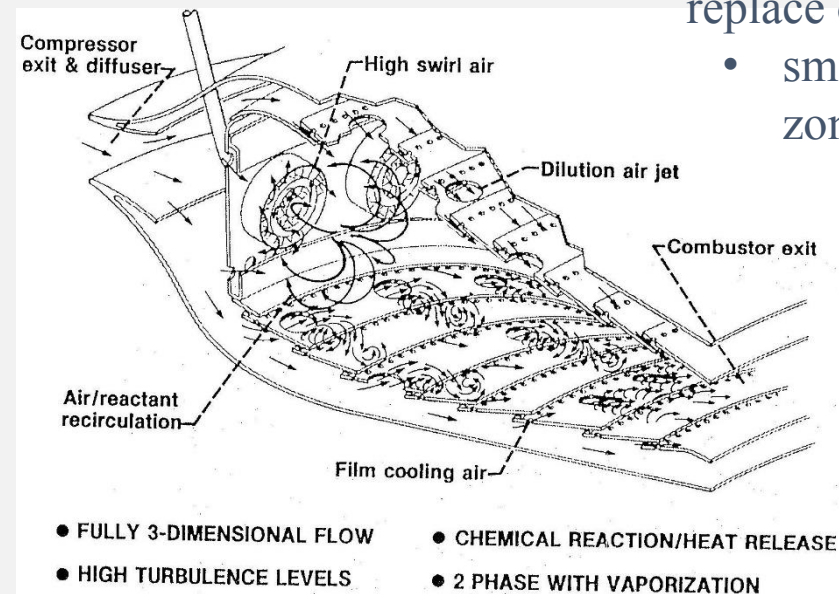
Lean Direct Injection (LDI) was developed and has been demonstrated as a scheme to reduce aircraft combustor NOx emissions while keeping CO and UHC's at current levels. It has been successfully used in NASA-sponsored HSR, AST, UEET, ERA programs.

The multiplex LDI scheme:

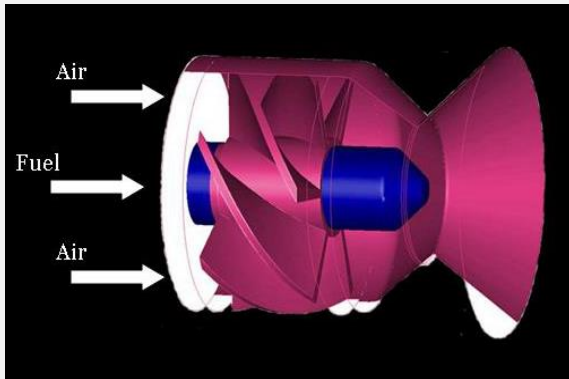
- Inject fuel directly into the flame zone
- Requires fine atomization and rapid mixing to assure fuel-air uniformity
- To enhance rapid mixing, several small fuel-air elements replace one injector
 - smaller elements also help support shortening the flame zone

Despite success, we need to better understand fuel vaporization, mixing, and combustion in order to facilitate the design process

- Use LDI to parametrically investigate the fluid dynamics of mixing and fuel injection. Consider swirler type, **swirl number**, **clocking**, number and size of elements, venturi size, fuel nozzle type, etc.



Baseline LDI element



- Six helical angled vanes
- Simplex atomizing nozzle
- Converging-Diverging Venturi

Swirlers: 45°, 52.5°, 60°

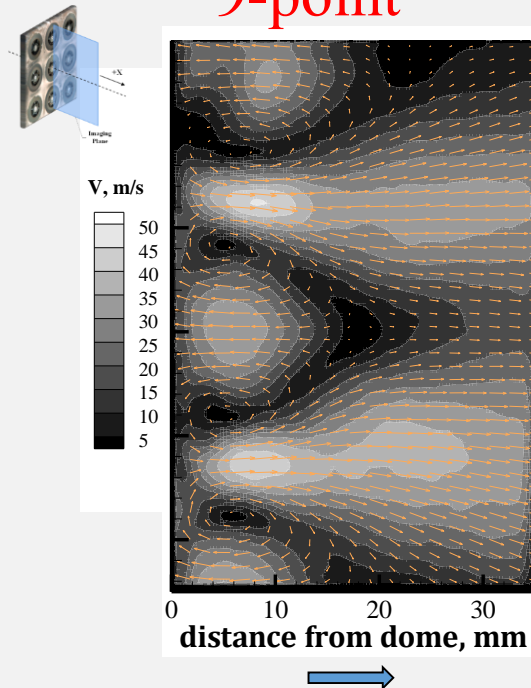
Swirl #s: 0.59, 0.77, 1.02

- 76.2 mm overall diameter
- 23.8 mm between adjacent elements
- Center can be offset upstream to act as a “pilot”

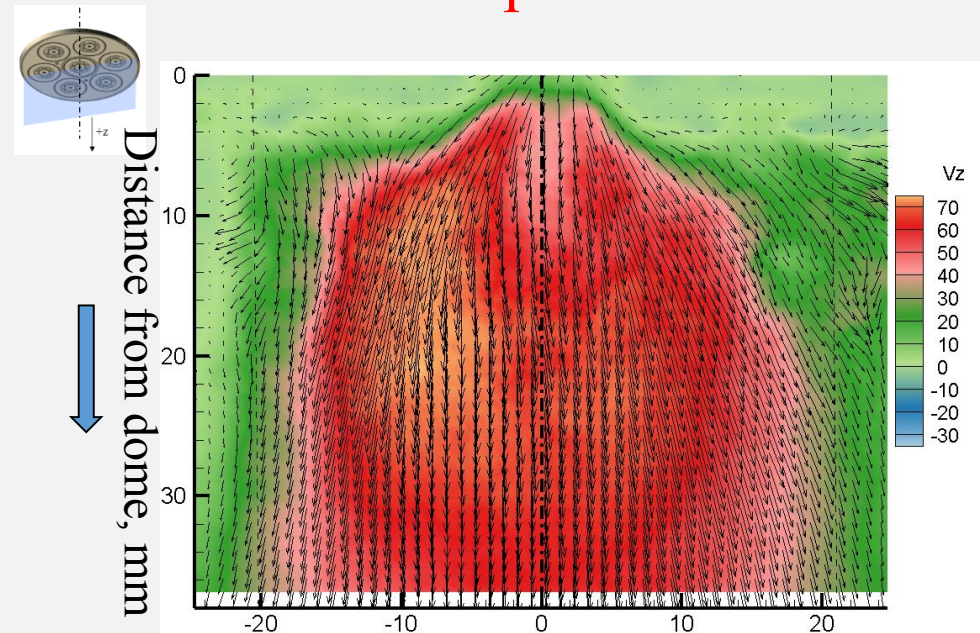
Recent History

- Began parametric study to observe flow field:
 - Varied swirler angle, clocking, spacing, using the 60° and 45° swirlers
 - Spacing and/or array-structure determines whether the CRZ forms
 - For 7-point, there seems to be strong interaction close to the dome, likely indicating the spacing is too close to produce CRZ behind all swirlers when using 60° swirler
 - Using the same swirlers in the 9-point which had larger spacing, a CRZ existed behind all

9-point



7-point



Present Work



Compare two 7-point configurations:

A: all counterclockwise (LH), 60° swirlers (baseline case)

B: center 60° RH swirler with six , outer 45° RH swirlers

Probe the entire optically-accessible volume to determine presence of recirculation zones and discern differences and similarities of the flow fields for the two configurations.

These cases are part of a systematic look at the effect of individual swirler orientation and adjacency on the fluid motion immediately following the dump plane for the 7point LDI.

The overall study will assist in understanding how to build future fixers for small core aircraft combustors.

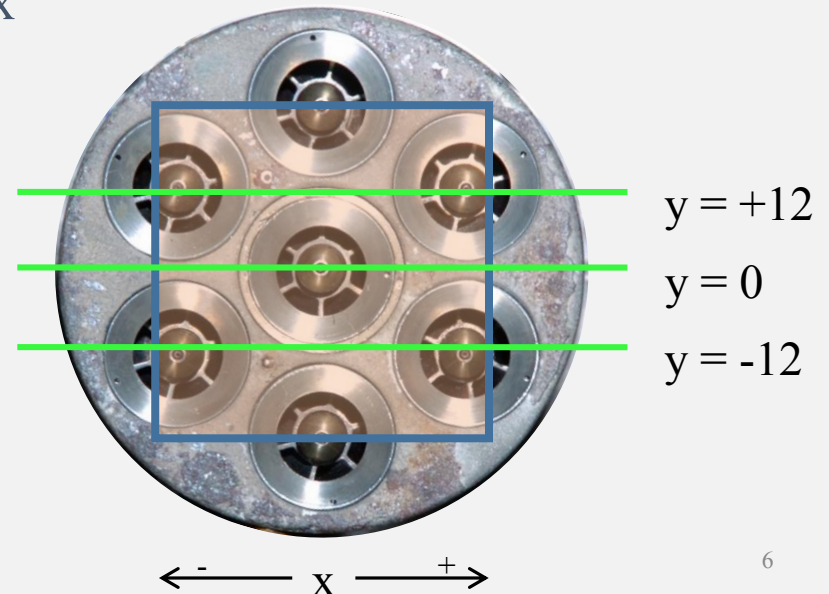
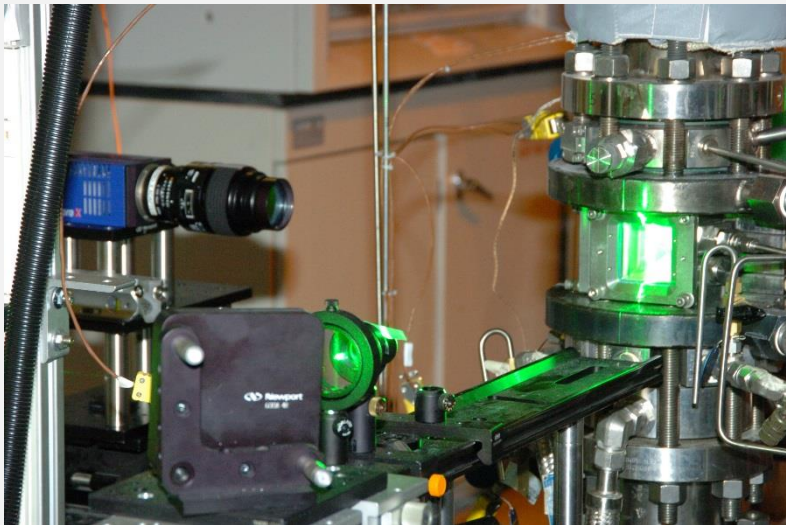
Measurement technique: water-seeded PIV



Water seeding keeps windows clean \therefore time to collect data at many locations

- Air inlet conditions: 5-bar, 700K
- Cold flow reference velocities: 22.9-m/s, 15.2-m/s
- Water seeding through the center nozzle
- Acquired 500 image pairs, $\Delta t = 5 - 10 \mu\text{s}$, typical
- Traverse in y- from -24 mm to +24 mm

PIV: 13 Hz dual head laser, 4-5 ns pulse width,
camera: interline transfer, 1600 x 1200 px



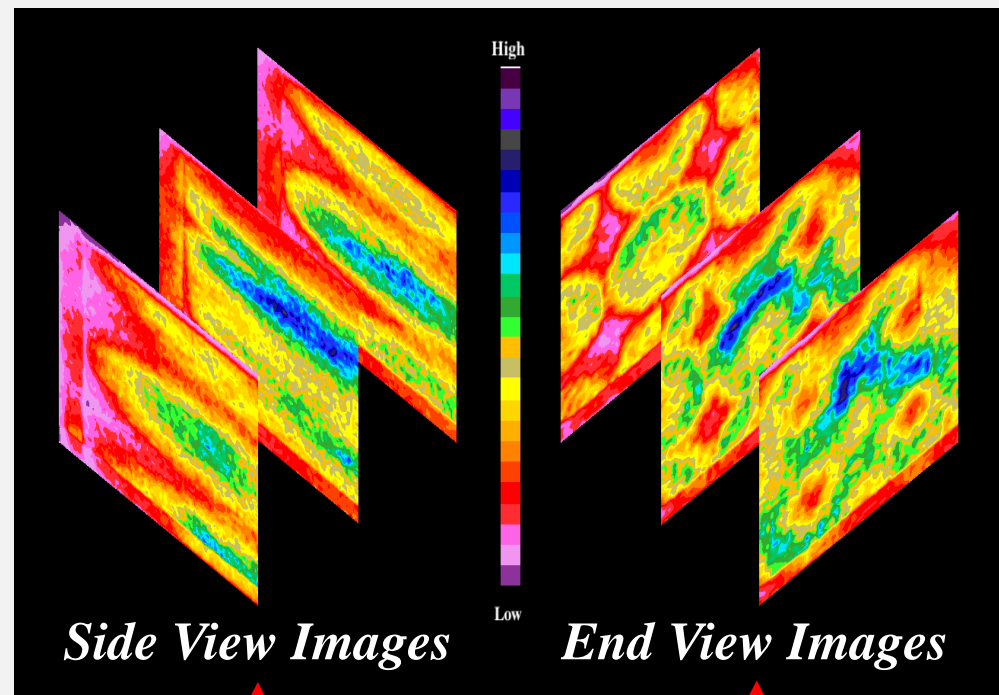
Example Results:

- Compare 2D, time-averaged velocity fields at $u_{\text{ref}} = 22.9$ m/s
- A look at the progression downstream of axial velocity

1. Begin with comparison at $Y = 0$
2. Look at Case A
3. Look at Case B

Result images either:

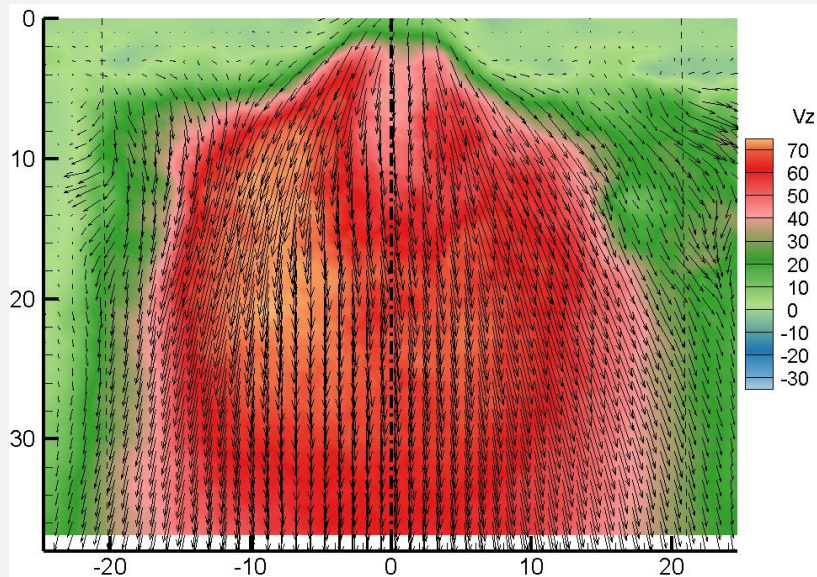
- side views as captured,
flow top to bottom
- end view composite slices
at fixed distances from exit,
flow out of page



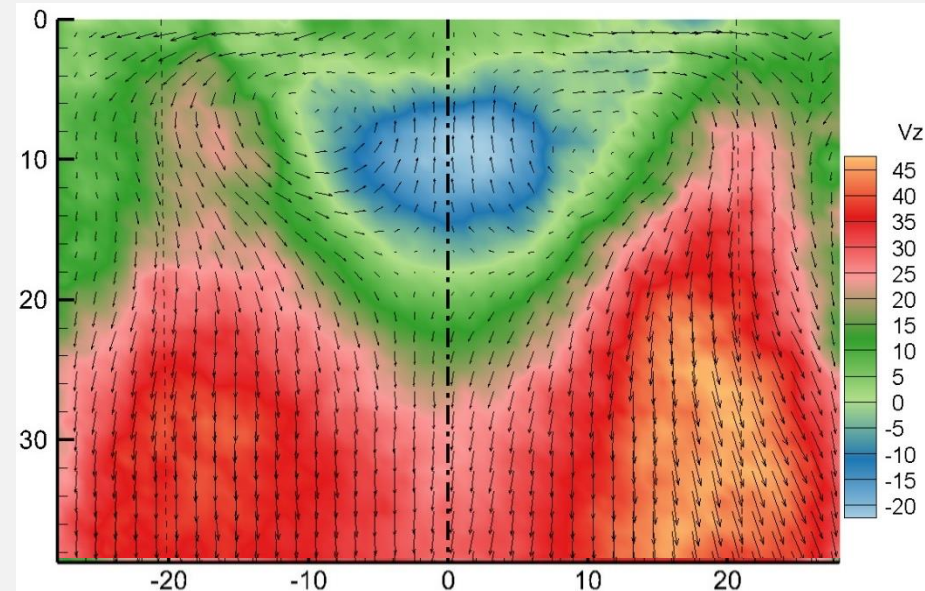
Images as captured Composite slices

Comparison at $Y = 0$

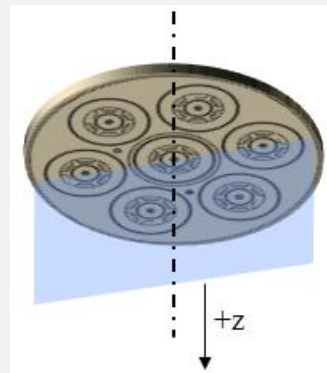
All LH60°



RH60°center, RH45°outer



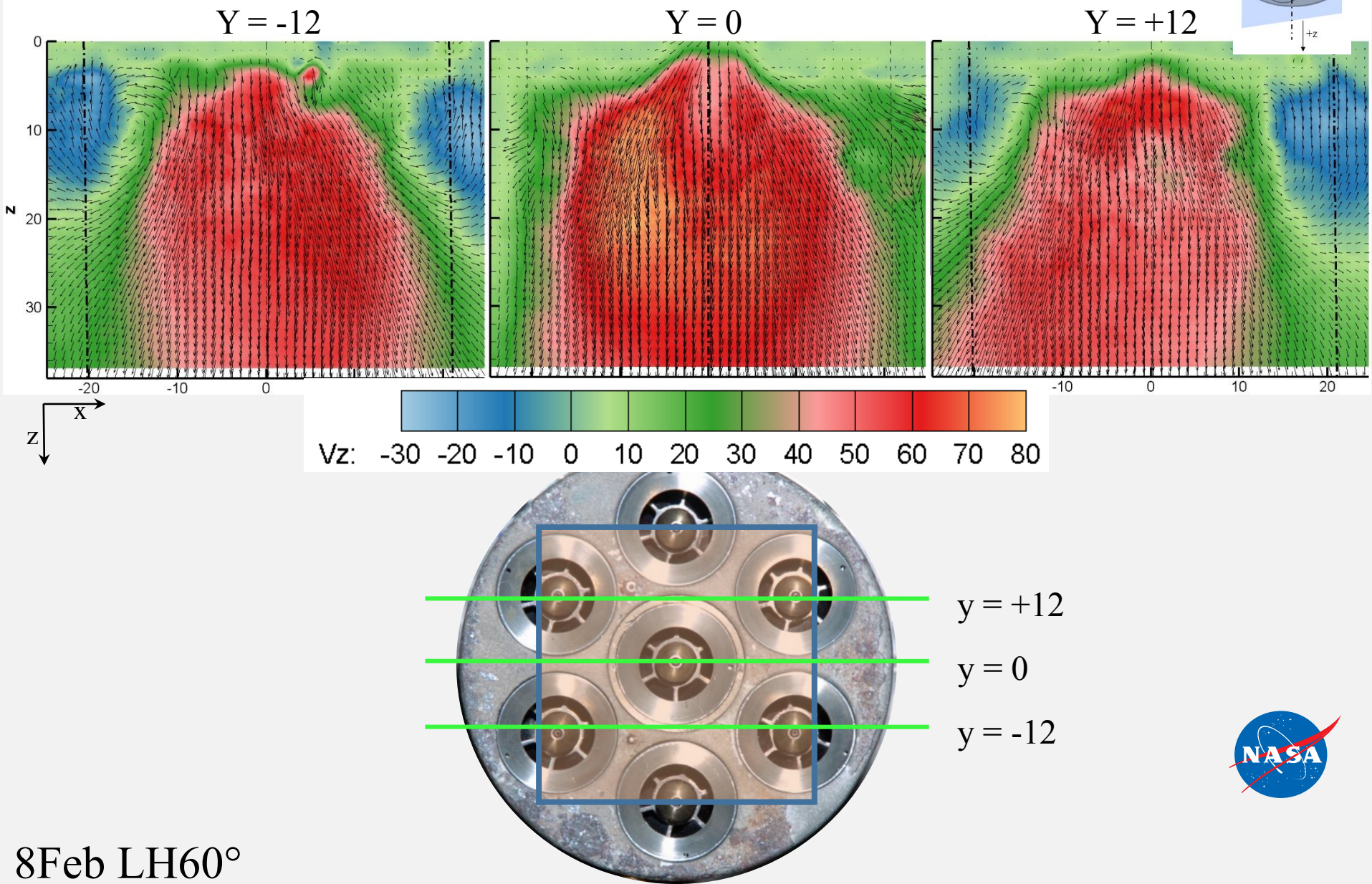
- No CRZ
- Max V_z near $y = 0$



- CRZ exists
- Relatively low V_z near $y = 0$

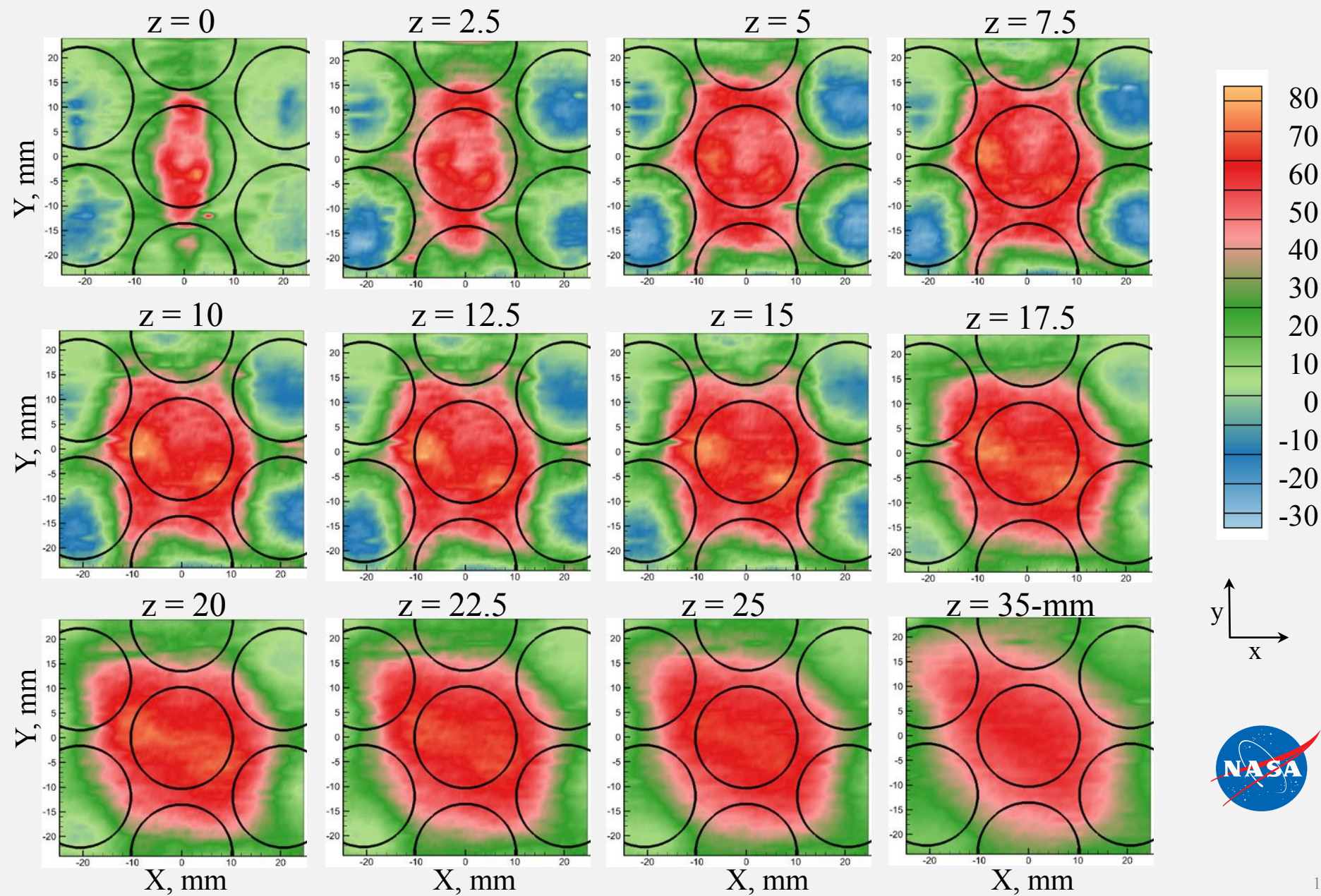
Horizontal-Axial Velocity profiles in three centerline positions in the field

Configuration A: LH60° swirlers



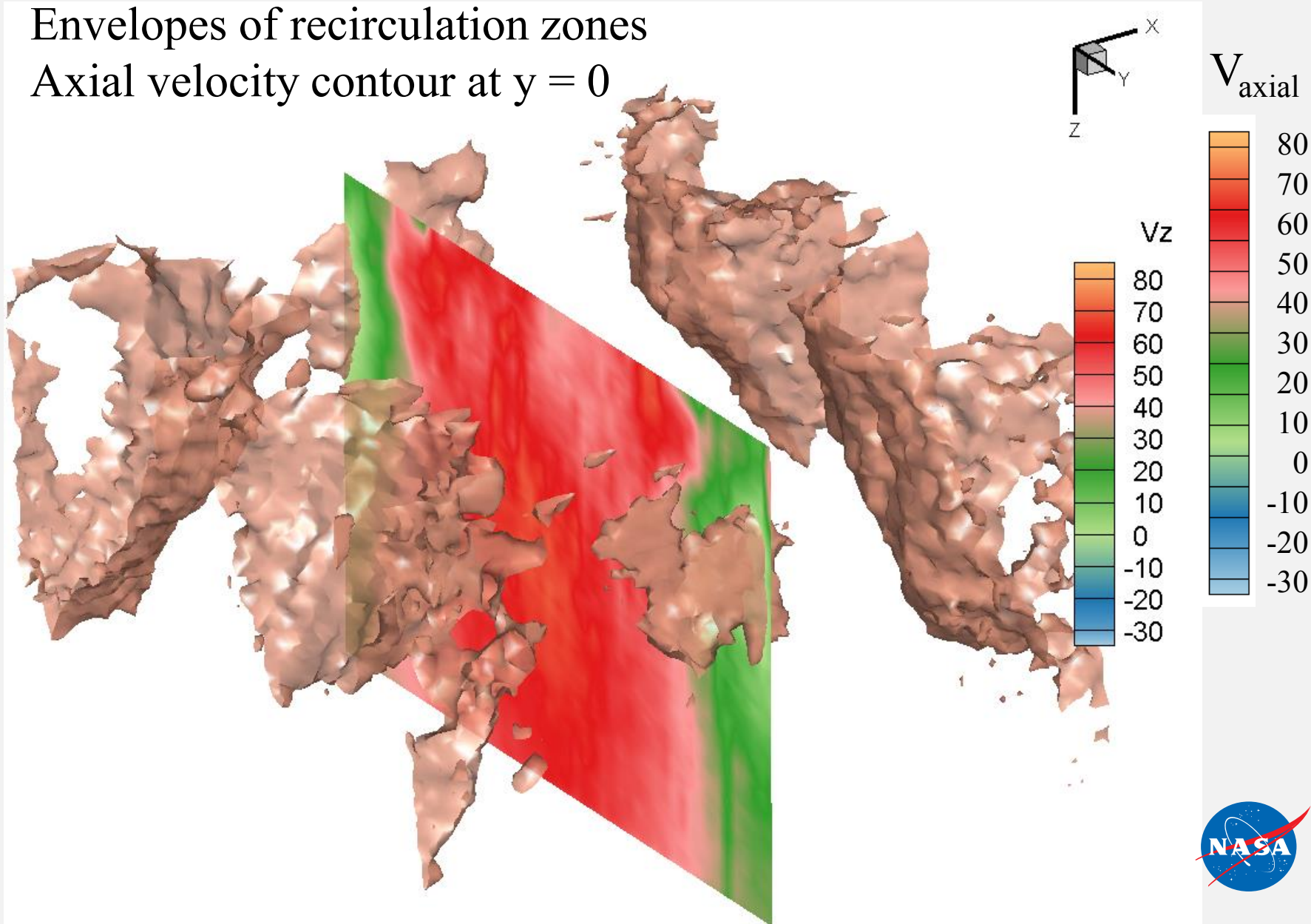
End views of axial velocity at various distances from dome exit

Configuration A: All counterclockwise 60° air swirlers



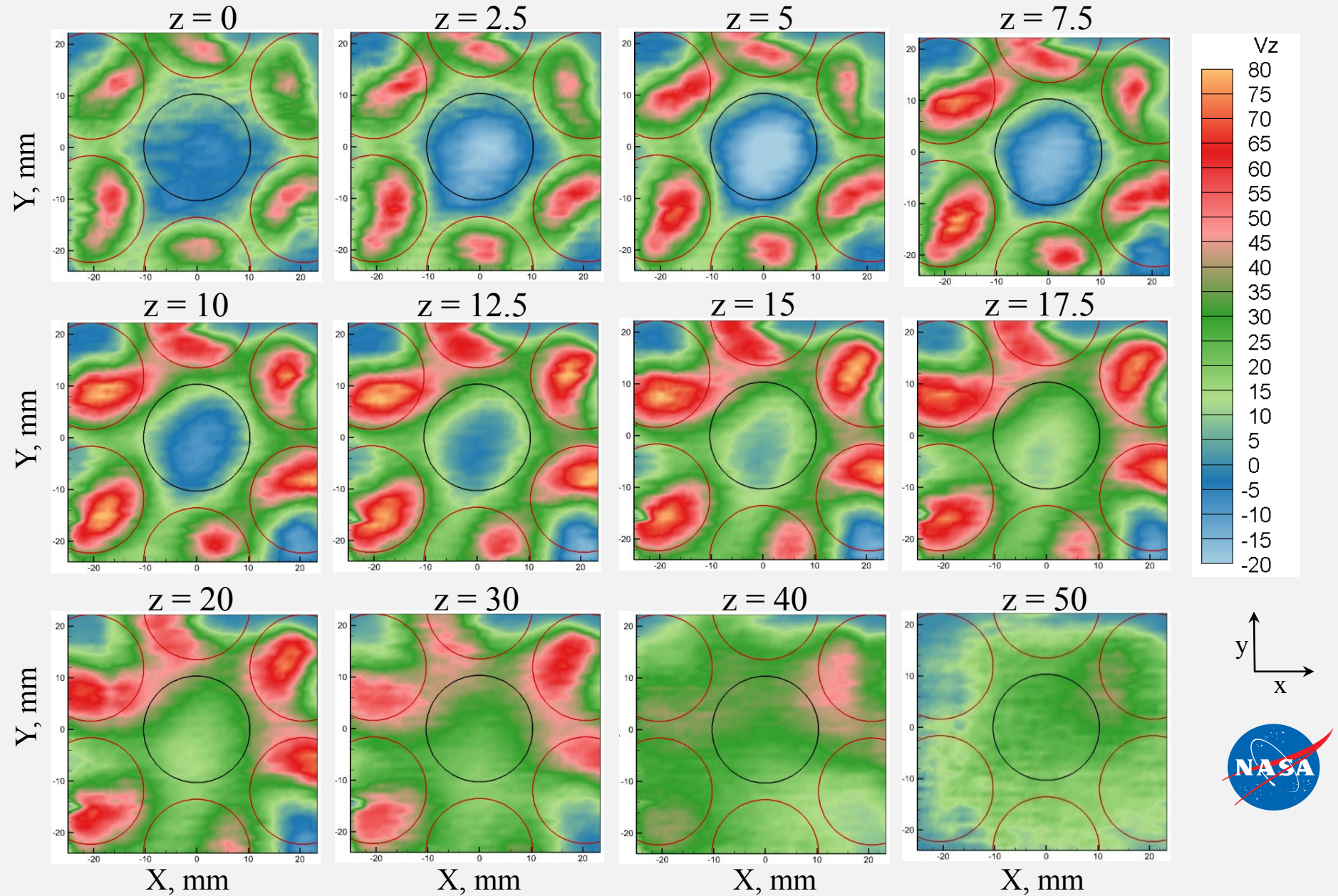
Configuration A—All 60° swirlers

- Envelopes of recirculation zones
- Axial velocity contour at $y = 0$



Swirler Configuration B: RH 60° center, RH 45° outer

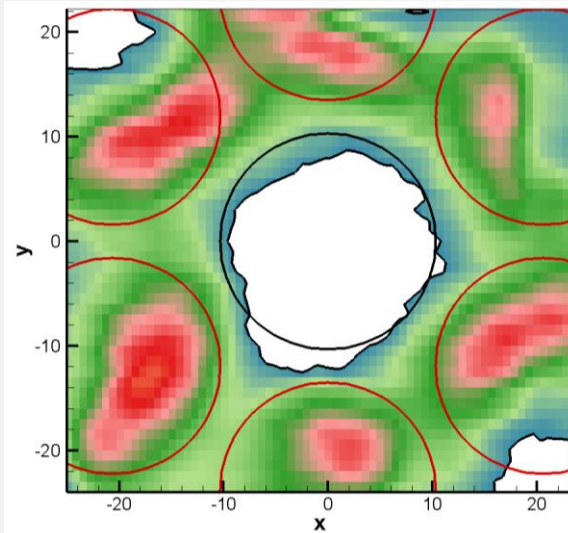
End views of axial velocity at various distances from dome exit



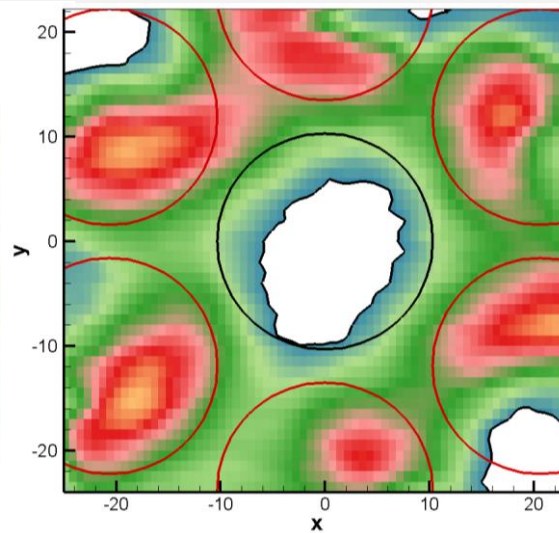
Configuration B—a closer look at selected axial slices

$V_{\text{axial}} < 0$ region in white

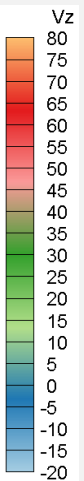
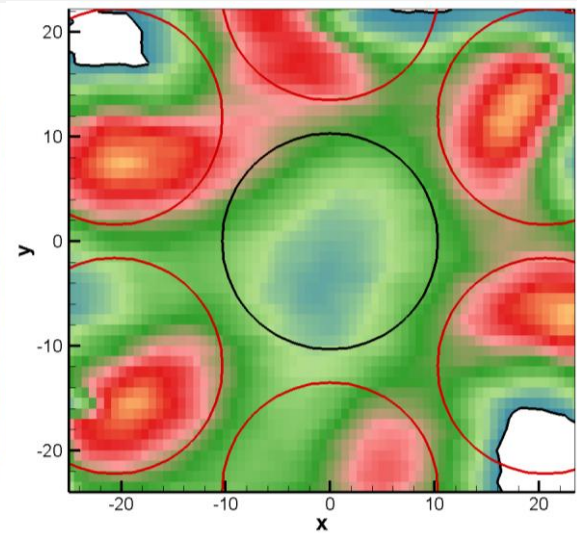
$Z = 10$



$Z = 15$



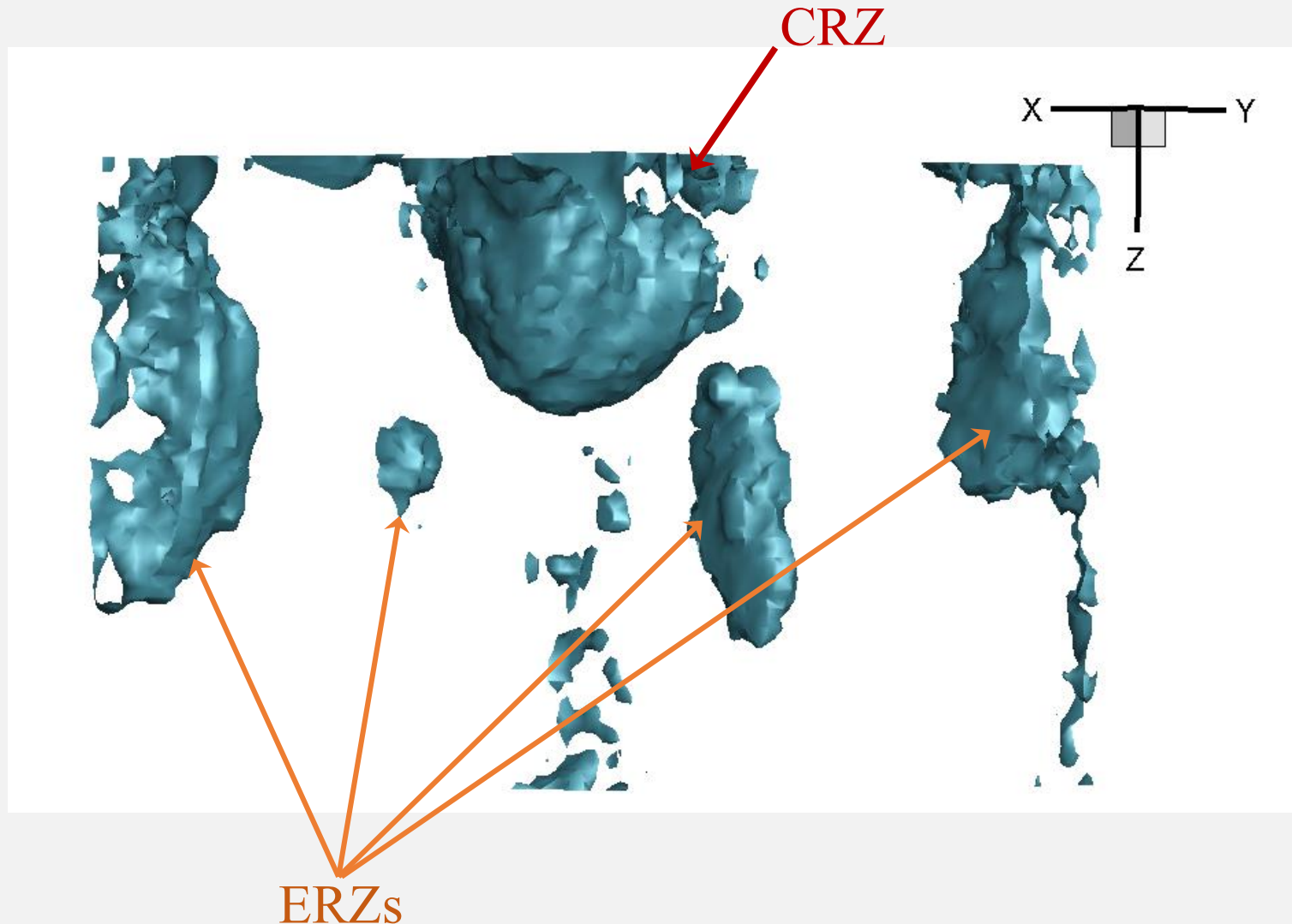
$Z = 20$



Configuration B—Center 60° , outer 45° swirlers

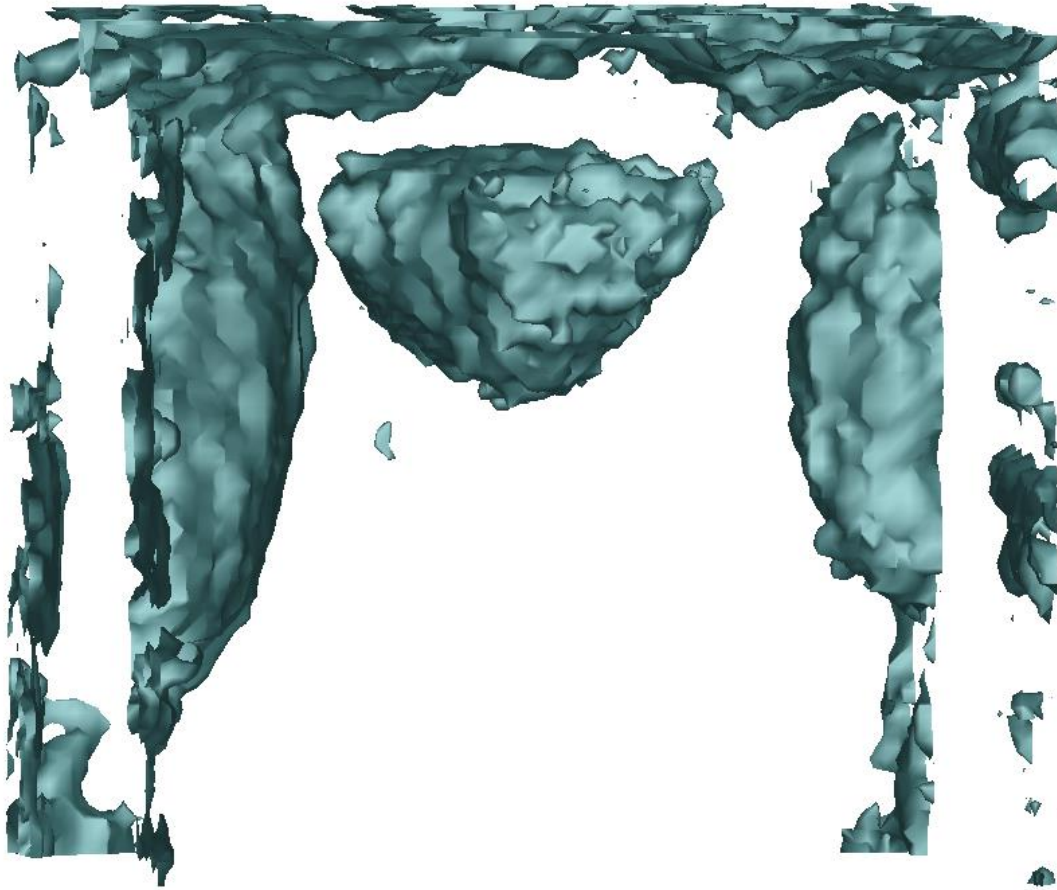


- Envelopes of recirculation zones, center (CRZ) and edge (ERZ)



Configuration B—Center 60° , outer 45° swirlers

- Envelopes of recirculation zones





Summary

Using PIV, we considered the axial velocity to determine whether and where central recirculation zones (CRZs) formed downstream from the injector elements.

We compared two configurations

A: the baseline case, with all counterclockwise (LH), 60° swirlers

B: center 60° RH swirler with six , outer 45° RH swirlers

For configuration A, a CRZ forms

- Always behind an outer 60° swirler
- Never behind the center swirler

Interaction between the elements counters the center swirl such that no CRZ forms



Summary, continued

For configuration B, a CRZ forms

- Always behind the center 60° swirler
- Never behind the outer 45° swirlers

BUT, a **corner** or **edge** recirculation region (ERZ) forms behind all outer swirlers. This zone is characterized by having its center near the outer edges of the 45° swirlers (relative to the 7-pt array centerline).

For the same ϕ , configuration A can support higher reference velocity than can configuration B.



Future Work

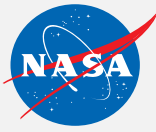
- Continue comparisons of configurations for non-burning and burning cases
- Investigate center recess effect
- Investigate the “size” and “strength” of the CRZs
- Select “best” cases for burning and emissions tests

We plan to use these and other results as a guide to design a new LDI injector.



Acknowledgment

- The NASA Fundamental Aeronautics Transformational Tools and Technologies Project supported this work.



Questions?